MULTIOBJECTIVE ANALYSIS OF NATIONAL TRANSPORT POLICY

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CERTIFICATE

Certified that this work on "Multiobjective Analysis of National Transport Policy", by Mr. T. Rajendran, has been carried out under my supervision and has not been submitted elsewhere for award of a degree.

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ABSTRACT

This thesis considers a multiobjective approach to the determination of optimal mix of different transportation modes. The modes considered include Rail (Electric and Diesel Traction) and Road transport systems. The objectives considered are the cost minimization, employment maximization and the minimization of energy consumption. In addition to the methodology, the ideas are illustrated with a network using representative but fictitious data. The multiobjective approach demonstrates that in a large scale system analysis project like this, consideration of single objective alone may be myopic.

1. INTRODUCTION

1.1 The Importance of Transport

Transport is the basic element of the infrastructure of economic development. The need for according high priority to transport sector stems from the size of the country as well as from the geographically dispersed natural resources. The key role of transport in development of the national economy has been undoubtedly recognized.

The significance of the transport sector lies not only in the specific services it renders, but even more in the unifying and integrating influence it exerts upon the economy; bringing rural areas and the more developed regions closer to one another enhancing productivity and stimulating the economic growth [26,1]*.

1.2 The Transportation System

The problems of designing a practical and useful transportation system-an entity composed of interdependent and interacting elements with a common goal-are many and varied. Among these problems are a number of initial conceptual problems. Even the term "transportation system" raises the question, is it a system at all? Transportation system is not isolated; it is in fact, interrelated with other major systems. The importance of this point is that

*Figures within brackets have the following meaning. The first entry refers to the reference number; the second (optional) entry refers to the page number in the cited reference.

community, regional and national planning must consider not only transportation issues, but issues related to other systems as well, calling for a comprehensive attack-the systems approach.

Transport investments are huge, amounting to a major share in plan outlays. Our Government has allocated Rs.5420 crores in the fifth five year plan (1974-79) and Rs.8621 crores in the sixth five year plan (1978-83) [30,1]. These figures indicate the magnitude of effort devoted for the development of the transport network and infrastructure. Naturally, transportation system is a representative large scale system.

The basic components of transport demand are <u>freight</u> and <u>passenger</u> traffic. These can again be classified as <u>inter-city</u> and <u>intra-city</u> traffic. Our transport network consists of various modes-the railways, the roadways, the airways, the waterways, the coastal shipping and the pipe line transportation. Out of this, the railways and roadways account for the major share both in investments and the traffic carried-70% of the total investments and more than 90% of the traffic as on 1977-78 [30,14] [2].

<u>Investment Planning</u> in transport sector has to take into account the following factors:

* Investments in transport are huge indivisible chunks.

* The long term nature of the transport investment introduces an element of risk and uncertainity.

* Investments in various modes of transport have different impacts on the socio-economic development of the country.

* The transport sector accounts for a sizable proportion of plan expenditures, and plays an important role in employment generation.

* The transport sector accounts for one third of the country's total commercial energy and more than half of its oil supplies [31,8].

Hence, an integrated macro-economic planning is vital for the transport sector. With many substantial interdependent projects, the transport planning needs a systems approach to achieve the desired levels of goals.

1.3 Our National Transport Policy

The three central issues to be considered in evolving an integrated framework for transport policy are

i) determination of the size of total transport investment

ii) distribution of this allotment between various modes of transport

iii) tariff for transport services.

For ii), the Planning Commission has planned to allocate rationally the total available resources for investment between various modes of transport. The allocation must match the growing requirements of the economy, keep in view the energy efficient modes and also minimize the user and operator costs. In addition, the following policy objectives have to be taken care of, for an integrated transport planning [30, 26]. The allocations must

* Maximize employment generation
* Minimize energy consumption
* Maximize the accessibility
* Maximize the economic development
* Maximize the comforts
* Minimize the pollution & environmental hazards.

The Planning Commission Report [30,6] suggests a systems approach to arrive at an optimal inter-modal mix in which the transport modes complement rather than substitute each other. The present policy of the Planning Commission is to

- appraise projects using resource costs,
- promote energy efficient modes and
- give more priority to freight transport.

1.4 Multiobjective Analysis

With the policy objectives quantified, multiobjective

analysis can be carried out for the present issue mentioned above. Multiobjective programming and planning is concerned with decision making in which objectives conflict each other. Since, the above objectives are conflicting in the transportation system, a multi-objective, macro level analysis will give more insight into the issue.

1.5 Outline of the thesis

This work outlines a multiobjective, static, macro-economic approach to transportation system planning. Chapter 1 deals with the importance of transport sector in economic development of the country and the need for multiobjective systems analysis for transport planning. In chapter 2, the problem of optimal inter modal mix is discussed; a brief review of the literature is given thereafter. Chapter 3 identifies the general objectives and discusses three major objectives that are considered in this analysis. Chapter 4 describes the formulation of a multiobjective programming model detailing the decision variables and constraints. Chapter 5 gives the details of a representative network considered for illustration and the input data requirements. The results obtained by solving the illustrative problem are subsequently discussed. Finally, the advantages of multiobjective analysis is pointed out and the further work that has to be done to implement and extend the model in practice is outlined.

2. PROBLEM STATEMENT & LITERATURE SURVEY

2.1 The Problem

The problem is to find an inter modal mix that will maximize the policy objectives. In other words, the problem is to find investment allocations between different modes of transport in the context of conflicting objectives.

As mentioned earlier, there are different modes of transport operating in our country. Railways and roadways together accounts for more than 70% of the investment and more 90% of the total freight and passenger traffic [30,14][2]. In turn, railways and roadways consume the maximum energy in the transport sector; considering the various modes of railways and roadways will give a good insight into the problem. Therefore, attention will be limited to these two sectors alone in this thesis.

2.1.1 The Methodology:

Either a topdown or bottom-up planning can be carried out; in top-down planning the information flows from the decision maker to the analyst; in bottom-up planning, the information flows from the analyst to the decision maker. In top-down analysis the decision maker explicitly gives his preferences and priorities; in bottom-up analysis, in the absence of preference, solutions are generated. This

analysis is a bottom-up macro-level analysis. The tradeoff functions and preference functions are not derived due to lack of data. Only some plausible solutions are generated.

2.1.2 Statement of the Problem:

We consider the problem of optimal expansion of the existing transportation system. The basic problem of planning link additions to an existing network can be considered as follows: Let the network be defined using ~~nodes~~ links that correspond to transport routes. Commodities to be transported are expected to enter the network at the nodes and travel from link to link to their respective destination nodes. Associated with each link is a cost incurred by a unit travelling over it as well as some fuel consumption. Also identified are the set of possible new links (or projects) from which link additions will be selected. The problem is one of selecting from the set of all feasible projects, that subset that minimizes the cost of using the overall network; or that subset that maximizes employment; or a subset that leads to minimum energy consumption.

2.2 Literature survey

A detailed description of systems analysis with case studies is given in De Neufville, R. and David H Marks [8]. Morlok [27], Meyer [26], Carter [4] and the CONSAD Research Publications [5] discuss various system models for transportation

planning. Dalvi's paper [7] deals with a macro-economic modelling for transport system. Roberts P.O. [33] has used mixed integer programming model for cost minimization.

Literature is rich in transport demand forecast, assignment models, trip generation & trip distribution and modal split models. Steenbrink [34] describes a stepwise assignment model; Other references in assignment models include Mathur, M.C. & others [24] Gartner, N.H. [15], Fisk Caroline [12]; references in modal split include Hasan Ibrahim & others [16], Florin, M. & others [13], Yashoshima, Y. [35], Abdulaal Mustafa & Larry J Leblanc [1].

All the above works pertain to single objective only. Multiobjective analysis of transport systems is relatively recent; for example, De Neufville R and Keeney R [9], Fisher M Franklin [11], Folk, J.F. & Joseph M Sussman [14], and Lee, S. [22].

The various multiobjective programming and analysis techniques are discussed in Keeny, R., and Raiffa H [18], Cohon, J.L. [6] and Rietveld Piet [32].

Papers that deal with transport policy and planning are: Agarwal A L & others [2] and Nordstran Lars [29]. The Planning Commission report [30] gives complete details of our transport policy, the studies carried out by RITES [30,30], NCAER [30,40] and NITIE [30,48], details about various models

and the pricing policy. Medhi, S B gives a detailed analysis of transport system and its development in Assam.

The user, operator and society cost are dealt with, in Mahajan [23], the RITES study [30,30] and Yasheshiv [35].

Energy implications in transport are dealt with, in Dodeja [10], the NITIE study [30,48] and the Planning Commission report on energy policy [31,50].

NCAER study [28] gives the employment generation in rail and roadways.

Bes K [3] gives a model for pollution due to various transport modes.

Jones [17] has given a literature review on accessibility measures.

The model that is formulated in this thesis is a network programming model furthering the ideas contained in Roberts, P.O. [33]. The multiobjective techniques are the generation techniques in Cohon J L [6,98].

3. MULTIOBJECTIVES IN TRANSPORTATION SYSTEMS

3.1 The Need for Multiobjective analysis

Multiobjective planning is concerned with decision making in which there are several conflicting objectives. Maximizing a single objective leads to the unambiguous identification of an "optimal" solution, which is invariably biased. The transport systems planning is characterized by a number of conflicting objectives; hence a multiobjective method presents a number of compromise solutions, presenting the decision maker a range of choice rather than just one "optimal" solution in taking decision. This aspect is perceived as an advantage.

Our policy objectives do conflict. This can be seen from Table 3.1. It shows the railways, especially electric traction are more energy efficient but the roadways are not. At the same time, the roadways generate more employment per unit of investment. Roadways provides more accessibility as it reaches nook and corner of the country. Both from the user and operator costs point of view, over short distance leads, roadways are cheaper but for long distance leads, railways are cheaper.

Mode	Energy consumption at the primary level BTU/Pass-km.	Employment Generation, man -years/crore of investment.
Diesel Rail	170	840
Electric Rail	158	NA
Highways (Diesel Bus)	315	1803

Source: [10] and NCAER study [28,41].

TABLE: 3.1 TRAVEL MODE COMPARISION: ROAD VS RAIL

(PASSENGER TRAFFIC)

In addition to conflicting objectives, the transport sector is characterized by its huge lumpsum investments. Hence the need for a multiobjective analysis in transportation systems planning can be summerised as follows.

- The policy objectives are conflicting
- The perception of the problem is more realistic in multiobjective analysis
- It provides a wide range of solutions.

3.2 Transport Policy Objectives

Our transport policy objectives can be listed as follows

1)Minimize user cost

2)Minimize operator cost

3)Minimize society cost

4)Maximize employment generation

5)Minimize energy consumption

6)Maximize the accessibility

7)Maximize the economic development

8)Maximize the comforts

9)Minimize pollution & environmental hazards.

Even though all the above objectives are important enough to be included in the analysis, due to lack of data and appropriate quantifiable models, only the following three major objectives are considered in this thesis.

i) Minimize the user cost and the operator cost

ii) Maximize the employment generation

iii) Minimize the energy consumption

3.3 Cost Minimization

This consists of three costs (i) The user cost, (ii) the operator cost and (iii) the social costs.

3.3.1 The User Cost:

Costs to the users are incurred by the users, namely, passengers, traders etc. For passenger traffic this consists of the cost that is incurred by passengers at terminals, the costs of the time spent in travelling, the degree of comfort. For freight traffic this can be quantified in terms of charges relating to packing, handling, local cartage, inventory holding etc. Hence, this cost is to be quantified in terms of cost/passenger-km for the passenger traffic and cost/ton-km for different commodities for freight traffic. This varies over distance slabs and is different for different modes.

3.3.2 The Operator Cost:

Cost to the operator consists of expenditures incurred in operating a transport network. These include repairs, maintenance and operating costs of rolling stock or vehicles as well as overhead costs. Operator cost has been calculated in terms of capital cost, interest and depreciation on assets,

other time-related charges like overhead expenditure, terminal costs, salaries of crew, repair and maintenance,and operating costs of rolling stock or vehicles. This again is quantified in terms of passenger-km for passenger traffic and ton-km for different commodities for freight traffic.

3.3.3 The Social Cost:

The social costs are the costs to the society, reflected in terms of disutility arising due to pollution, noise, congestic accidents etc. This cost is not included in the objective function due to lack of quantitative data.

The need for minimizing these costs is obvious as the users and operators are directly incurring these costs.

3.3.4 The RITES Study:

In the RITES (Rail India Technical & Economic Services Ltd.) study, the estimation of operator and user costs for all the commodities moving by rail and road have been grouped into 13 relatively homogeneous categories represented by wheat, cotton (raw), potatoes, coal, fertilizer, sugar, petroleum products, tea, cotton textiles, cement, livestock, steel tubes and pipes, and small machineries. The estimation was carried out for passenger flow also. Cost estimation for six railway situations - diesel single line block load, diesel single line wagon load, diesel double line block load, diesel double line wagon load, electric double line block load

and electric double line wagon load and two highways situations were carried out. These data are available in [30,74].

3.4 Employment Maximization

3.4.1 Employment Generation:

The transport sector accounts for a sizable proportion of plan expenditure and plays an important role in generating employment. Total employment generated through investment in transport takes two forms:

- direct and
- indirect

Direct employment is created both in the construction phase of the establishment and subsequently in its operation. In the construction phase, duration of employment is for the period until the plant is ready to be operated.

Indirect employment, on the other hand, is induced by and thereby causally related to direct employment in an industry either through a chain of backward or forward linkages. The backward chain of linkages starts with material and service inputs used either in the establishment or operation of the industry. Each of these inputs has to be produced, which causes additional man-power to be employed. The chain continues since in production of the first stage inputs, other inputs may be required, which, in turn, need to be produced.

Indirect employment also arises through another set of chain reactions. At each forward or backward link, employment creates income and therefore, purchasing power which is expended on consumer goods in the production of which further employment is generated. The employment through additional income and consumption occurs both through forward and backward linkages and direct employment.

As one proceeds along the forward and backward linkages, there are leakages which weaken the original impetus for the generation of employment. These leakages on the material side occur due to use of imported items, which generate employment and income only in their countries of origin, and also through savings which abstract a part of the income leaving at each stage a smaller amount available for consumption. As a consequence of these leakages, the stream of employment and income generation weakens as one proceeds away from the industry where direct employment is created [28.3].

By segmenting the construction work as survey, earthwork, compaction...etc [28,14], the employment per km of construction of railway track or highways can be determined. Similarly for manufacture of rolling stock, vehicles, locomotives and for maintenance of permanent way, rolling stock, signal and telecommunication, terminal buildings each is individually estimated and summed up.

With a high rate of unemployment both at regional and national level, it becomes extremely necessary to consider this objective in planning huge investments.

3.4.2 The NCAER study:

The study carried out by the NCAER (National Council of Applied Economic Research) on the employment potential in roadways and railways gives the data for each segment of direct and indirect employment generation. Employment due to track construction and maintenance is given in man-years per km of construction as well as in terms of investment. Employment generated due to the other sectors is given in terms of the passenger and goods flow. However, the goods have not been classified into groups. Different commodities require different amount of transport requirements and these in turn, will generate different degrees of employment. The figures available in NCAER study [28,1] are representative macro figures and do not give the break-up within each mode as well as break-up by commodities.

3.5 Minimization of Energy Consumption

3.5.1 Energy Consumption:

Rail, road and air transportation consume 80% of commercial energy consumed and is the single largest sector in the use of petroleum based energy in our country [10]. In conserving energy in transport sector two things have to be

taken care of :

1. Maximize the Utilization of available energy resources and
2. Promote energy efficient modes.

Electric traction is based on indigenous resources and is more economical compared to diesel traction. Road transport consumes more than 80% of the diesel oil in the country and is fully dependent on oil. It is necessary to have a brief look at the energy efficiencies of various modes on a common unit basis. It is also more relevant not only to look into the energy needed at the point of consumptions, but also the levels of energy needed as input at the primary source of conversion, such as the power plants [10].

Energy is consumed in propulsion and non-propulsion. This can be measured in terms of BTU per passenger-km or ton-km. At the primary level, we have

- power generation by coal fired power station
- hydro power station
- thermal power generation.
- power generation with diesel oil.

We have to account for the thermal efficiencies and transmission losses in comparing the energy consumption at primary level.

3.5.2 The NITIE study:

The NITIE study carried out for the planning commission gives the data for propulsive and non propulsive power consumption. These figures have not been converted to the primary level. Conversion can be done using the figures in [10] or [31,114].

In considering this objective in our model, the energy consumption at the primary level has been taken into account. But, this takes care of the second portion of our objective only; "Maximizing the use of available resources" is not taken into account in our model.

4. MULTIOBJECTIVE PROGRAMMING MODEL

4.1 Introduction

The multiobjective programming model that is proposed is formulated as a bottom-up, macro-economic, static, network analysis with the following objectives :

1. User and operator cost minimization
2. Maximization of employment and
3. Minimization of energy consumption

The decision problem is conceived as one of selecting a subset of projects from a list of prospective candidate projects, to augment an existing network. The selection has to satisfy the traffic demand requirements, the capacity restrictions and optimize the chosen objectives.

The proposed model would be for a inter-city traffic and assumes that the traffic would originate and terminate at nodal points only. It will also be assumed that the per unit cost of transportation or the per unit employment generation or per unit energy consumption, does not vary with the flow volume. Notransshipment costs are included.

Between the same pair of nodes alternate projects may be considered (say Rail or Road); also the flow may be in one or both the directions. For notational simplification each mode will be considered as a link for each direction-

making the network-multiedge network (non-standard).

The following constraints should be met :

i) all supplies and demands of each commodity type must be met by flow over the network in which the sum of flows into each node, must equal to the sum of flows going out,

ii) if a link is not built there can be no flow over it,

iii) the amount of funds committed to building new projects must not exceed the available budget,

iv) the project must either be considered or not; that is, partial construction of a project is not permitted.

4.2 Decision Variables

In the statement of the model the flow values (continuous) are denoted by x_j's and the decision variable (0 or 1), that decides, whether or not a project is undertaken, is denoted by y. All the links are numbered sequentially; subscript denotes the link, while superscript denotes the commodities; passenger flow is denoted by p_j's ; no superscript is used for passenger flow.

4.3 Objectives

4.3.1 Cost Minimization:

The basic components of cost are the user cost u and operator cost v. If u_j^k and v_j^k are respectively the user and

operator cost, of transporting a ton of commodity k in route j expressed as Rs./ton of commodity k and u_j and v_j are the user and operator costs for passenger transport in route j, the objective function for cost minimization can be expressed as:

$$\text{Min } Z_1 = \sum_k \sum_j (u_j^k + v_j^k)\, x_j^k + \sum_j (u_j + v_j) p_j \qquad (4.1)$$

where, x_j^k and p_j denote the flow of commodity k and flow of passengers respectively over link (route) j.

4.3.2 Employment Maximization:

Employment is generated due to construction of new routes, flow of commodities and passenger traffic in routes. If a_j denotes the employment due to construction of route j, and y_j is the (0,1) decision variable for selecting the route j, the employment due to construction is,

$$\sum_{j \in \bar{J}} a_j y_j$$

where,

$\bar{J}$ = set of proposed routes.

Denoting the employment due to manufacturing and operation of rolling stock or vehicles in route j as.

i) b_j^k & c_j^k for transporting a ton of commodity k in route j and

ii) b_j & c_j for transporting a passenger in route j,

we have the employment generated due to freight and passenger traffic as,

$$\sum_j \sum_k (b_j^k + c_j^k)\, x_j^k + \sum_j (b_j + c_j)\, p_j$$

Hence the objective function for employment generation is,

$$\text{Max } Z_2 = \sum_{j \varepsilon \bar{J}} a_j y_j + \sum_j \sum_k (b_j^k + c_j^k)\, x_j^k + \sum_j (b_j + c_j)\, p_j \qquad (4.2)$$

where,

$\bar{J}$ is the set of proposed links.

4.3.3 Energy Consumption:

Energy consumption can be expressed as the summation of the propulsive & non propulsive energy requirements in transporting the commodities and the passengers in the routes. Let d denotes the propulsion component and e denotes the non-propulsion component [30,40]; the energy requirements, can be represented as

$$\text{Min} \quad Z_3 = \sum_j \sum_k (d_j^k + e_j^k)\, x_j^k + \sum_j (d_j + e_j)\, p_j \qquad (4.3)$$

4.4 Constraints

The major constraints for any transport network are the flow constraints, the capacity constraints and the budget constraint .

4.4.1 The Flow Constraint :

Since traffic is assumed to originate and terminate at nodes only, the flow of goods and passengers from and into a node should be equal to the actual originating freight traffic f_i^k and terminating freight traffic g_i^k and passenger originating traffic f_i and passenger terminating traffic g_i at node i. For each node i we have the following constraints :

$$\sum_{j \varepsilon I(i)} x_j^k = f_i^k \qquad \forall\, k \qquad (4.4)$$

$$\sum_{j \varepsilon \bar{I}(i)} x_j^k = g_i^k \qquad \forall\, k \qquad (4.5)$$

$$\sum_{j \varepsilon I(i)} p_j = f_i \qquad (4.6)$$

$$\sum_{j \in \overline{I}(i)} p_j = g_i \tag{4.7}$$

where,

$\overline{I}(i)$ denotes the set of all incoming links at node i

$I(i)$ denotes the set of all outgoing links at node i.

4.4.2 The Capacity Constraints :

The commodities flow and the passenger flow should not exceed the freight capacity and passenger capacity respectively. The capacity of a route is taken as the minimum of the line capacity and the rolling stock capacity. If,

r_j denotes the freight capacity of route j and

s_j denotes the passenger capacity of route j,

then,

$$\sum_k x_j^k - r_j y_j \leqslant 0 \qquad j \varepsilon \overline{J} \tag{4.8}$$

$$\sum_k x_j^k \leqslant r_j \qquad \forall\ j \tag{4.9}$$

$$p_j - s_j y_j \leqslant 0 \qquad j \varepsilon \overline{J} \tag{4.10}$$

$$p_j \leqslant s_j \qquad \forall\ j \tag{4.11}$$

$\bar{J}$ is the set of proposed links (routes).

4.4.3 The budget Constraint :

The investments in project costs q_j have to be within the available budget B.

$$\text{(i-e)} \quad \sum_{j} y_j q_j \leqslant B \tag{4.12}$$

Note:

Project cost q_j includes the investments both in the forward traffic flow and backward traffic flow links (routes). Care is taken to ensure that both the forward and backward links are considered together for selection; investments in both the links constitute q_j, the project cost.

Additional Note:

Increasing the line capacity or the rolling stock capacity of an already existing route, can be taken as an additional new route with appropriate objective function coefficients, capacities and project costs. Similarly, electrifying an existing diesel track or doubling the tracks or increasing the number of lanes in highways can be viewed as an additional route.

4.5 The Multiobjective Model

With the above mentioned objectives and constraints, the problem becomes a mixed integer multiobjective programming

model which can be written as,

$$\text{Min } Z = \left\{ Z_1(X,Y),\ -Z_2(X,Y),\ Z_3(X,Y) \right\}$$

$$\text{s.t} \quad (X,Y) \varepsilon\ F \tag{4.13}$$

Z_1, Z_2 and Z_3 are the objective functions defined in (4.1) to (4.3). F is the feasible region defined by the constraints (4.4 to 4.12), X is the vector of flow variables (continuous) and Y is the set of choice variables (binary).

First, we optimize the individual objective functions and see the relative role of each objective in the solutions. Next, to derive the relative tradeoff between the objectives, one of the objective is kept fixed. Of the remaining two objectives one is constrained to take values in a range and the other objective is optimized. By parametrically varying the ranges over which the objective is constrained, a set of points can be obtained that reveal the relative tradeoff between the two objectives. This tradeoff curve is called Transformation Curve in literature [6,98]. Mathamatically,

$$\text{Max } Z_2(X,Y)$$

$$\text{s.t.} \quad (X,Y) \varepsilon\ F$$

$$Z_1 = k_1$$

$$Z_3 \geqslant k_3 \tag{4.14}$$

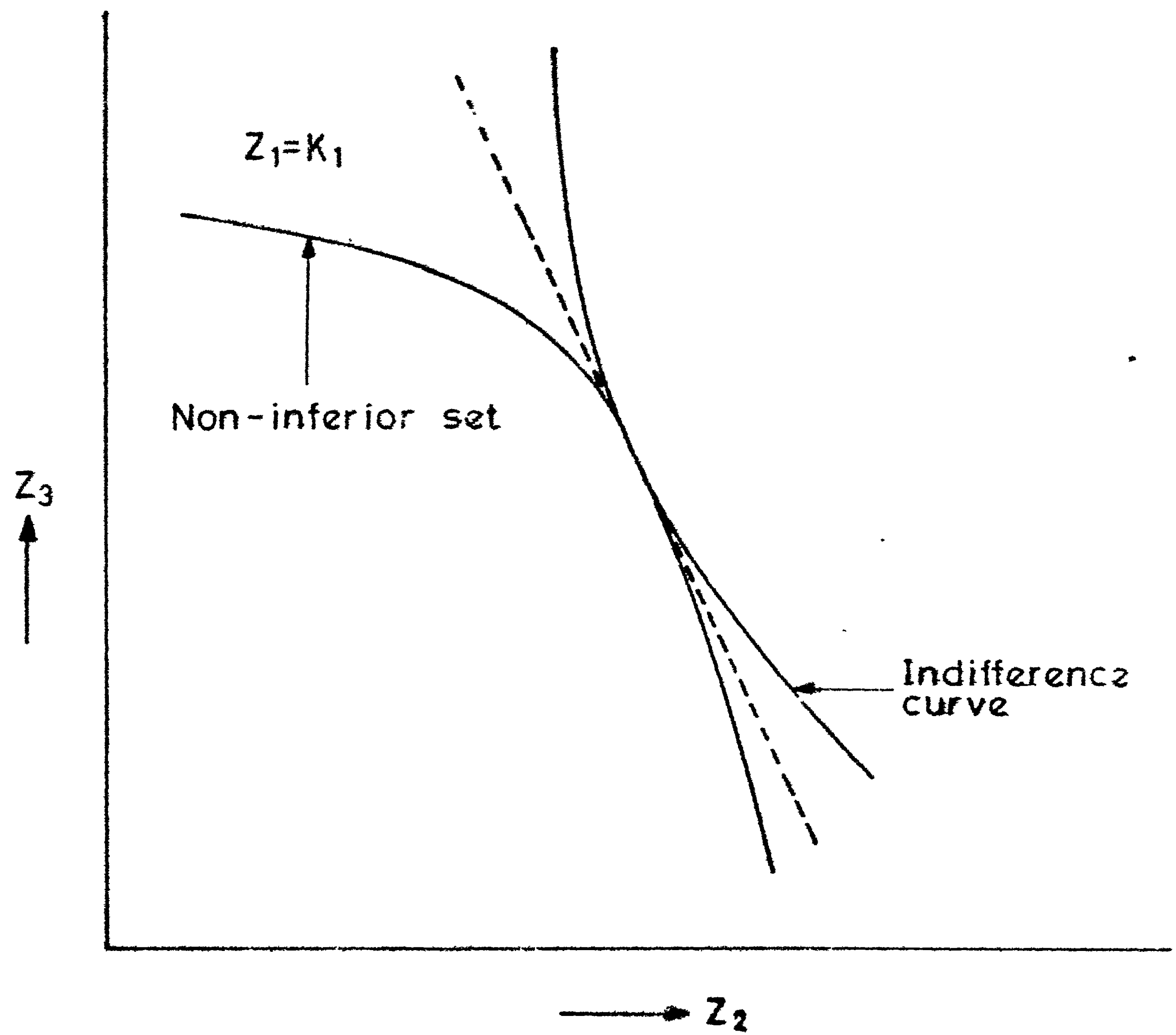


Fig. 4·1 The transformation curve

where k_1 is the level at which objective Z_1 is fixed; k_3 is the level over which objective Z_3 isparametrically constrained.A typical transformation curve is shown in fig. 4.1. A similar transformation curve can be drawn for other pairs of objectives also.

There are many other methods to generate the relative tradeoff functions. Methods incorporating "generating techniques" include :

i) The NISE method

ii) Multiobjective simplex method.

Methods incorporating preferences are :

i) Multiattribute utility theory

ii) The goal programming

iii) The surrogate worth tradeoff method.

We limit ourselves to only generating transformation curve.

5. ILLUSTRATIVE EXAMPLE

5.1 Illustrative Example

5.1.1 The Network:

A representative network with fictious data, as shown in fig. 5.1 is considered for illustration. There are 14 pairs of existing routes (one for forward flow and the other for backward flow) and 5 pairs of proposed routes. The existing network consists of 4 pairs of diesel rail double track, 2 pairs of electric rail double track, 8 pairs of national highways. A single commodity, namely, "steel tubes & pipes" is assumed to flow in the network.

Distance, mode and capacity for all the routes are given in Table 5.1. The project costs of the proposed routes are given in Table 5.2. Table 5.3 gives the originating and terminating traffic at each node. All these data are suitably assumed.

5.1.2 Input Data:

The objective function coefficients for the three objectives are given in Table 5.6. Table 5.4 gives the basic data for the objective function coefficients for different modes. The data for the user and operator cost per ton-km is calculated using the equations in this table. These equations are obtained by fitting a st. line between the

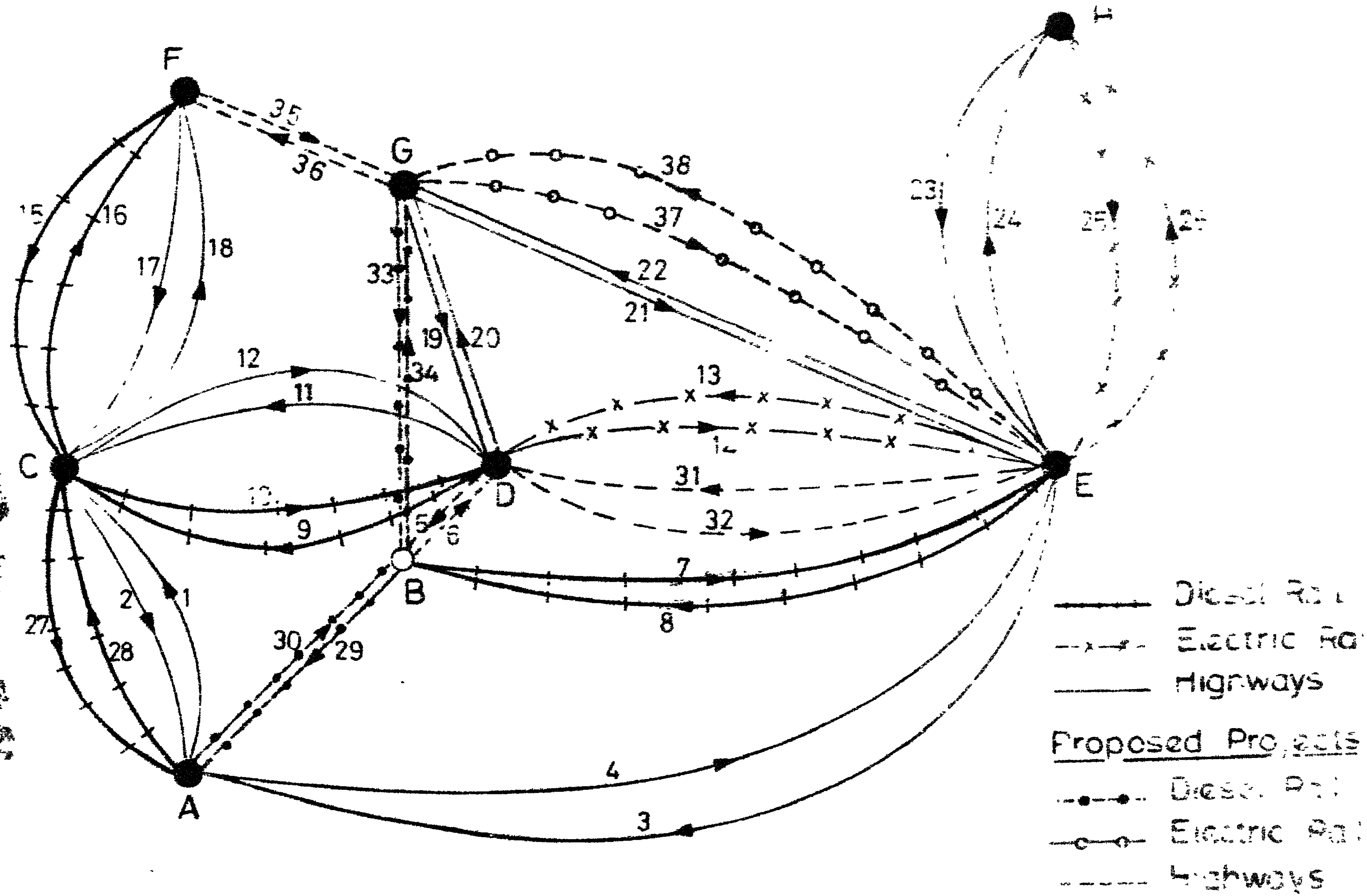


Fig.5·1 The network

ROUTES	DISTANCE '000 Kms	MODE	FRIEGHT CAPACIT '000 ton
1,2	350	HIGHWAYS	450
3,4	680	HIGHWAYS	450
5,6	160	HIGHWAYS	450
7,8	420	DIESEL RAIL	550
9,10	300	DIESEL RAIL	550
11,12	300	HIGHWAYS	450
13,14	290	ELECTRIC RAIL	650
15,16	400	DIESEL RAIL	550
17,18	400	HIGHWAYS	450
19,20	260	HIGHWAYS	450
21,22	340	HIGHWAYS	450
23,24	520	HIGHWAYS	450
25,26	520	ELECTRIC RAIL	650
27,28	350	DIESEL RAIL	550
29,30*	300	DIESEL RAIL	550
31,32*	290	HIGHWAYS	450
33,34*	380	DIESEL RAIL	550
35,36*	320	HIGHWAYS	450
37,38*	340	ELECTRIC RAIL	650

*Proposed projects.

Table: 5.1 NETWORK DETAILS

Proposed Routes	Investment for each route Rs. in crores
29,30	0.69
31,32	0.348
33,34	0.874
35,36	0.384
37,38	1.02

TABLE 5.2 PROJECT COSTS FOR THE PROPOSED ROUTES

Nodes	Originating Traffic '000 tons	Terminating Traffic '000 tons
A	1291	1209
B	946	1136
C	1371	1030
D	2300	2400
E	2959	2849
F	483	469
G	923	1105
H	550	625

TABLE : 5.3 ORIGINATING AND TERMINATING TRAFFIC AT NODES

Mode	User + Operator cost functions[1] Rs/ton	Employment Generation[2]		Energy consumption due to propulsion (primary level) BTU/ton-km[3]	Investment Rs/km Rs in crores
		Construction Man-yrs/crore	Operation man-yrs/ton-km		
DIESEL RAIL	69.36 + 0.08 x DISTANCE	840	0.00842	288	0.23
ELECTRIC RAIL	69.28 + [illegible] x DISTANCE	750*	0.01032	214	0.30
HIGHWAYS	[illegible] x DISTANCE	[illegible]	0.02095	1796	0.12

* Suitably assumed

Source: 1. Planning commission Report [30,77]

2. NCAER Study [28,2]

3. Planning commission Report [30,43] and [10]

TABLE : 5.4 BASIC DATA FOR OBJECTIVE FUNCTION CALCULATIONS

ROUTES	EMPLOYMENT due to INVESTMENTS Man-yrs
29,30	289.8
31,32	313.72
33,34	367.08
35,36	346.175
37,38	382.5*

* Suitably assumed

Source: NCAER Study [28,2]

TABLE: 5.5 EMPLOYMENT DUE TO INVESTMENTS

Routes	User and Operator Cost[1] Rs./ton	Employment Generation[2] man-yrs/ton	Energy Consumption[3] BTU/ton
1,2	41.97	0.07423	6.251
3,4	58.47	0.14421	12.144
5,6	32,47	0.03393	2.857
7,8	51.48	0.03876	1.209
9,10	46.68	0.02769	0.864
11,12	39.47	0.06362	5.358
13,14	41.89	0.02995*	0.707
14,16	15.68	0.03692	1.152
17,18	44.47	0.08483	7.144
19,20	37.37	0.05514	4.643
21,22	41.47	0.07211	6.072
23,24	50.47	0.11028	9.287
25,26	47.64	0.05371*	1.268
27,28	48.68	0.03230	1.008
29,30	46.68	0.02769	0.864
31,32	38.97	0.06150	5.179
33,34	49.88	0.03507	1.094
35,36	40.47	0.06786	5.7152
37,38	43.14	0.03512*	0.829

*Suitably assumed

Source: 1. Planning Commission Report [30,77]

2. NCAER study [22,2]

3. Planning Commission Report [30,43] and [10]

TABLE: 5.6 OBJECTIVE FUNCTION COEFFICIENTS

cost and distance that are available in [30,77]. The objective function coefficients for employment due to operation and maintenance and employment due to construction are available in [28,2] and Table 5.5. Table 5.4, the basic data for objective function coefficients, has the energy consumption due to propulsion; non-propulsive energy consumption is not included in the analysis.

5.2 Solutions:

Using the branch and bound code [20,66], the problem is solved for,

i) each objective seperately
ii) by constraining the objectives.

Solutions, by optimizing each objective individually, are given in Tables 5.7 to 5.9. Each table gives the flow in each route, the choice of the proposed routes, the impact of this solution with respect to other objectives and the share of different modes.

Next, solutions are obtained by maximizing employment generation, by fixing the cost at a certain level and by parametrically varying the energy consumption. Two sets of solutions, by keeping cost at Rs47.5 crs. and Rs47 crs. are obtained. The figures are given in Tables 6.4 and [6.5]. The points are plotted to represent the transformation curves.

Commodity Flow						Selected Routes	Objective Function Values (x10^3)
Route	Flow '000tons	Foute	Flow '000tons	Route (Proposed)	Flow '000tons		
1	500	14	513	27	291	Diesel	COST : Rs.475170
2	500	16	0	30	0	Diesel	EMPLOYMENT: 2770 man-yrs
3	500	17	275	31	500	Highways	ENERGY CONSUMPTION: 54534 BTU
4	500	18	99	32	500	Highways	
5	500	19	500	33	0	Diesel	
6	500	20	500	34	36	Diesel	SHARES OF MODES
7	600	21	221	35	384	Highways	DIESEL RAIL : 1582 (14.61%)
8	446	22	193	36	194	Highways	ELECTRIC RAIL:1348 (12.45%)
9	0	23	500	37	0		HIGHWAYS: 7893 (72.94%)
10	0	24	500	38	0		
11	387	25	125				
12	140	26	50				
13	660	27	291				
14	513	28	209				

TABLE: 5.8 SOLUTIONS BY MAXIMIZING EMPLOYMENT

Commodity Flow						Selected Routes	Objective Function Values (x10^3)
ute	Flow '000tons	Route	Flow '000tons	Route (Proposed)	Flow '000tons		
1	0	15	469	29	600	Diesel	COST : Rs.485889
2	0	16	483	30	569	Diesel	EMPLOYMENT: 2491 man-yrs
3	479	17	0	31	500	Highways	ENERGY CONSUMPTION: 27658 BTU
4	338	18	0	32	500	Highways	
5	377	19	445	33	0		
6	360	20	263	34	0		SHARES OF MODES
7	176	21	0	35	0		DIESEL RAIL: 3744 (34.61%
8	0	22	0	36	0		ELECTRIC RAIL:3815(35.26%
9	600	23	0	37	660	Electric	HIGHWAYS: 3262 (30.15%)
0	335	24	0	38	660	Electric	
1	0	25	625				
2	0	26	550				
3	660	27	212				
4	660	28	302				

TABLE: 5.9 SOLUTIONS BY MINIMIZING ENERGY CONSUMPTION

6. DISCUSSION OF RESULTS AND CONCLUSION

6.1 The Results

The flows in the routes and the choices among proposed routes are obtained by

i) minimizing the user and operator costs

ii) maximizing the employment generation

iii) minimizing the energy consumption (at the primary level).

Sets of points representing the transformation curves for th employment generation vs energy consumption at two levels of cost, at Rs. 47 crores and at Rs.47.5 crores are obtained by solving the multiobjective programming model (4.13).

6.1.1 Conflicting nature of the objectives:

The solutions obtained show substantial differences illustrating the conflicting nature of the objectives. Tabl 6.2 shows the quantum of conflicts between the objectives. A normalized table is obtained from 6.2, by normalizing the objective function value z by,

$$z_{norm} = \frac{z - z^*}{z^*}$$

where,

z^* is the optimum objective function value. The rela conflicts among the three objectives, clearly shows that al

Modes / Solution	Diesel Rail	Electric Rail	Highways
COST MINIMIZATION	1082 (9.99)	2955 (27.32)	6786 (62.69)
EMPLOYMENT MAXIMIZATION	1582 (14.61)	1348 (12.45)	7893 (72.94)
ENERGY MINIMIZATION	3744 (34.61)	3815 (35.24)	3262 (30.15)

Figures in parentheses represent percentage share

TABLE: 6.1 SHARE OF MODES

(Commodity Flow in '000 tons)

Objective	Cost Rs$(x10^3)$	Employment man-yrs $(x10^3)$	Energy Consump BTU (x1
Cost Minimization	464823	2628	45553
Employment Maximization	475170	2770	54534
Energy Consumption	485889	2491	27658

TABLE: 6.2 OBJECTIVE FUNCTION VALUES

Objective	Cost Rs$(x10^3)$	Employment man-yrs $(x10^3)$	Energy Consump BTU (x1
Cost Minimization	0	0.05126	0.6470
Employment Maximization	0.02226	0	0.9717
Energy Consumption	0.04532	0.01007	0

TABLE: 6.3 NORMALIZED OBJECTIVE FUNCTION VALUES

the three objectives are conflicting one another at various degrees. (Table 6.3).

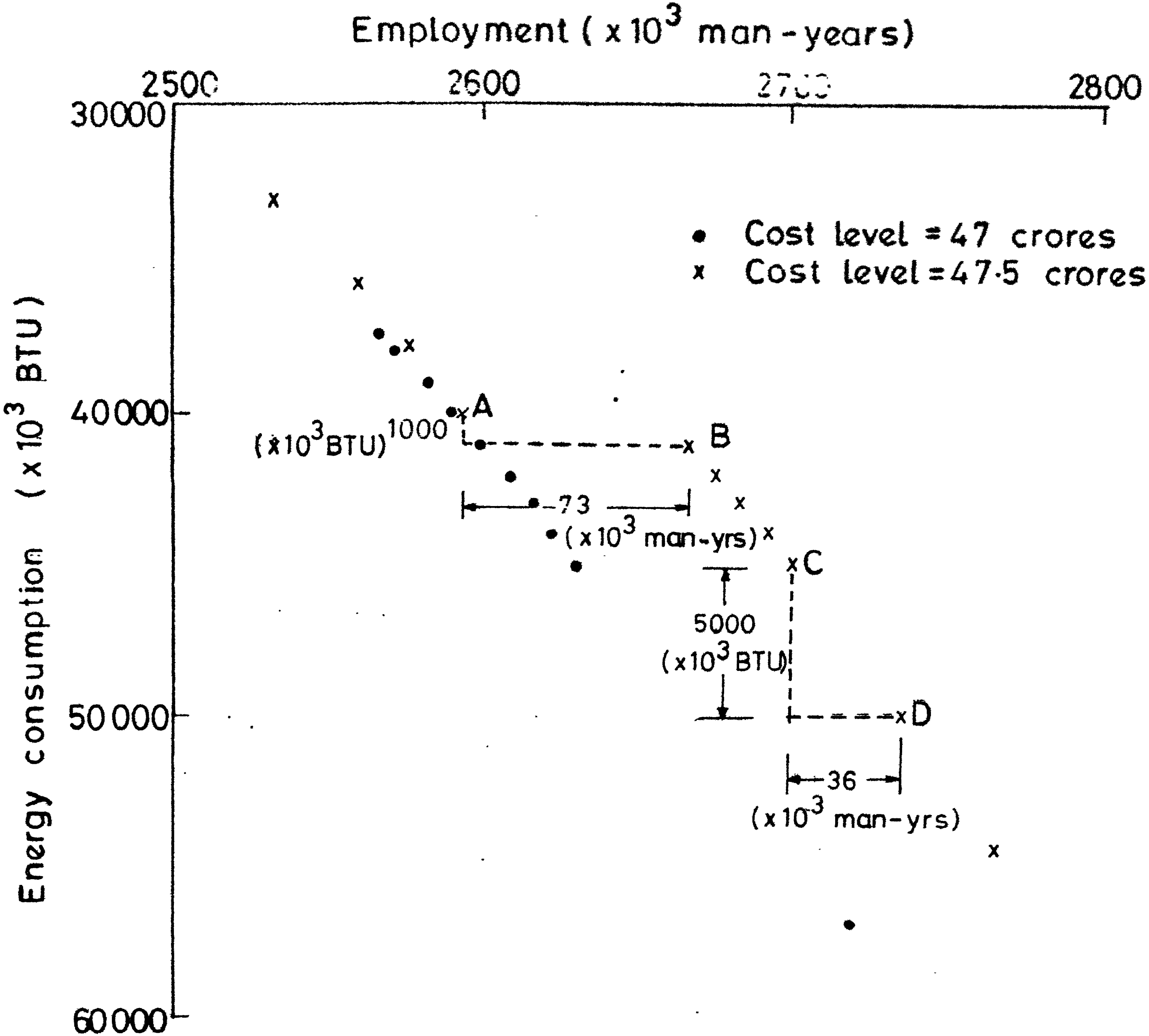
6.1.2 Share of Modes:

The amount of freight carried by each mode and the percentage share of these modes are given in Table 6.1 for the solutions obtained by i) minimizing the user + operator costs, ii) maximizing the employment generation and iii) minimizing the fuel consumption. If a decision is made with respect to a single objective, the modal mix is going to be substantially different from other solutions. One of the main issues of the Planning Commission is to come out with a modal mix optimizing the above mentioned objectives. The figures in Table 6.1 show that modal mix will be drastically affected by the objective considered. Hence, a detailed analysis considering the policy objectives is a must for a compromising modal mix.

6.1.3 The Transformation Curve:

The sets of points depicting the transformation curve in Fig 6.1 illustrates the conflicting nature of the objectives with one another. Employment generation can be increased only by trading off the increase in energy consumption. Cost considerably increases for an increase in employment generation and decrease in energy consumption.

The points in Fig 6.1 do give an idea about the



Employment (x 10^3 man - years)
2500
2600
2700
2800
30000
40000
50000
60000
Energy consumption (x 10^3 BTU)
Cost level = 47 crores
Cost level = 47·5 crores
A
B
C
D
(x10^3 BTU) 1000
73
(x 10^3 man-yrs)
5000
(x10^3 BTU)
36
(x 10^3 man-yrs)

Solution	Cost Rs $(x10^3)$	Employment man-yrs $(x10^3)$	Energy Consumption BTU $(x10^3)$
Solution 1	475000	2769	54470
Solution 2	475000	2532	33130
Solution 3	475000	2559	36000
Solution 4	475000	2577	38000
Solution 5	475000	2586	39000
Solution 6	475000	2594	40000
Solution 7	475000	2667	41000
Solution 8	475000	2676	42000
Solution 9	475000	2685	43000
Solution 10	475000	2694	44000
Solution 11	475000	2703	45000
Solution 12	475000	2739	50000

TABLE: 6.4 EMPLOYMENT VS ENERGY CONSUMPTION: TRANSFORMATION AT COST = Rs.47.5 crores

Solution	Cost Rs $(x10^3)$	Employment man-yrs $(x10^3)$	Energy Consumption BTU $(x10^3)$
Solution 1	470000	2712	56716
Solution 2	470000	2567	37435
Solution 3	470000	2572	38000
Solution 4	470000	2582	39000
Solution 5	470000	2591	40000
Solution 6	470000	2600	41000
Solution 7	470000	2609	42000
Solution 8	470000	2617	43000
Solution 9	470000	2625	44000
Solution 10	470000	2632	45000
Solution 11	470000	2667	50000

TABLE: 6.5 EMPLOYMENT VS ENERGY CONSUMPTION: TRANSFORMATION AT COST = Rs.47 crores

tradeoffs. In moving from C to D, with cost fixed at Rs.47.5 crores we are able to achieve an additional 36,000 man-years of employment at the cost of an additional 50,00,000 BTU energy consumption.

The "elbow" region shown by the points A and B in Fig 6.1 at cost level Rs. 47.5 crores is of particular interest. In moving from A to B we can increase employment by 76000 m-yrs at a marginal additional energy consumption of only 1×10^6 BTU, which is much more than what we could achieve in moving from C to D. It pays to identify such regions, where we can considerably increase an objective for relatively smaller tradeoff.

Similarly, discrete points representing the transformation curve for the other pairs of objectives can be obtained and analysed for the tradeoffs.

6.2 Conclusions and recommendations

A modest attempt has been made to justify the use of multiobjective analysis for planning the national transport policy. Using a set of representative data on a very limited network the claim is established quantitatively. The results of this preliminary analysis show the strong conflicts involved in the objectives considered. Naturally, solutions that differ substantially in modal mix could be obtained by consideration of the various objectives independently. A

compromising solution that incorporates the policy planners relative preferences for the various objectives would be far superior to a myopic approach that considers only the cost aspect in isolation.

Due to time and resource limitations, the analysis has been limited to a very simple illustrative case. Extensive data collection and validation for costs, employment and energy, modewise and commoditywise must be undertaken before a detailed study can be carried out. Also, the alternatives and objectives that have been considered in the illustrative example could be considerably expanded to account for all realistic situations. Since our objective in this study has been more to justify the use of multiobjective analysis rather than a multiobjective analysis itself these limitations could not be avoided.

Computationally, solving the problem for the full scale national network could be very demanding. More efficient computational procedures including heuristics might have to be designed to overcome the computational difficulties.

REFERENCES

(1) Abdulaal Mustafa and Larry J Leblanc, "Methods for Combining model split and equilibrium assignment models", Transportation Science, Vol: 13, No: 4 (Nov 79) p 292.

(2) Agarwal, A.L., Ramji Pathak, G.C. Tewari and Anurag Mishra, "Trends in transport development and transport development policies in India", National Symposium on Transportation System Studies, I.I.T. Delhi (Dec 1981) ppM58.

(3) Bez, K., "Mathamatical model for environmental planning with reference to pollution by the transport sector of the economy", National Symposium on Transportation Studies, I.I.T. Delhi (Dec 1981) p F7.

(4) Carter, E.C. and Wolfgang S.H., "Introduction to transportation engineering", Reston Publishing Company Inc., Virginia (1978).

(5) CONSAD Research Corporation, "Impact Studies; Northeast Corridor Transportation Project Vol II," CONSAD Research Corporation, Pennsylvania.

(6) Cohon, J.L., "Multiobjective Programming and Planning", Academic Press (1978).

(7) Dalvi, M.Q., and Tarun Das, "Transport Modelling at at Macro Level: Some results for India", International Conference on Transportation Vol I (Nov 80) p TP-1.

(8) De Neufville, R., and David H Marks, "Systems Planning and Design", Prentice-Hall Inc. (1974).

(9) De Neufville, R., and Keeney, R., "Multiattribute Preference Analysis for Transportation Systems Evaluatio Transportation Research 7 (1973) p 63.

(10) Dodeja, G. P., "Energy Implications and Related Issues in Transport", National Symposium on Transportation system Studies, I.I.T. Delhi (Dec 81) p F23.

(11) Fisher, F.M., "The Survival of the Passenger Train: The Demand for Rail road Passenger Transportation betwee Boston and New York", Systems Planning and Design, Prenti Hall Inc (ed: De Neufville R. & D.H. Marks)(1974) pp 136

(12) Fisk Caroline, "Some Developments in Equilibrium Traffic Assignment", Transportation Research, Vol: 14B (Sep 80) pp 243-255.

(13) Florian, M., R Chaplean, S. Nguyen, C. Achim, L. James and J. Lefebore, "A planning method for multi-modal urban transportation systems", Transport decisions in an age of uncertainty (ed : E J Visser) (Apr 77) pp 512-518

(14) Folk, J.F., and Joseph M Sussman, "Unreliability in Railroa Network Operations", Systems Planning and Design, Prentice-Hall Inc., (ed: De Neufville R & D.H. Marks) (1974) pp 273-288.

(15) Gartner, N.H., "Optimal Traffic Assignment with Elastic Demands", Transportation Science, Vol : 14 No: 2 (May 80) pp 174-207.

(16) Hasan Ibrahim and Antti Talvitie, "An equilibrium mode-split model of work trips along a transportation corridor", Transport Decisions in an age of Uncertainty, (ed: E J Visser) (Apr 77) pp 129-136.

(17) Jones, S. R., "Accessibility measures : a literature review", Transport and Road Research Laboratory Report No: 967 (1981).

(18) Keeney, R., and Raiffa, H.,"Decisions with Multiple Objectives: Preferences and Value Tradeoffs", Wiley, N.Y. (1976).

(19) Kisan, C. L., "Railway Traction Strategy-Future Inland Transportation", International Conference on Transportatio Vol: I (Nov-80).

(20) Kuester, J.L., and Joe H Mize, "Optimization Techniques with Fortran", McGraw-Hill Book Company (1973).

(21) Lansdowne, Z.F., "Rail Traffic Assignment", Transportation Research A Vol: 15A (Mar-81) pp 183-190.

(22) Lee, S., "Goal Programming for ~~Decision~~ Transportation Analysis", AIIE Transactions, Vol: 5 No: 4 (1973) pp 333-338.

(23) Mahajan, M.B., "Modal Flows and Resource Costs", National Symposium on Transportation System Studies, I.I.T. Delhi (Dec-81) p C84.

(24) Mathur, M.C., and P.S. Satsangi, "Entropy Maximizing Metho and Kirchhoffs Generalized Postulates in Traffic Assignment Process", National Symposium on Transportation System Studies, I.I.T. Delhi (Dec-81)

(25) Medhi, S.B., "Transportation System and Economic Development in Assam", Publication Board, Assam (1978).

(26) Meyer J., "Techniques of Transport Planning", The Brookings Institution, N.Y. (1971).

(27) Morlok, E.K., "Introduction to transportation engineering a Planning", McGraw-Hill, N.Y. (1978).

(28) NCAER, "Employment Potential of Rail and Road Transport", National Council of Applied Economic Research, New Delhi (1980).

(29) Nordström Lars, "Traffic research relating to both short-term and long-term traffic planning", Transport Decisions in an age of Uncertainty (ed: E J Visser) (Apr 77).

(30) Planning Commission, "Report of the National Transport Policy Committee", Government of India, Planning Commissio New Delhi (May 80).

(31) Planning Commission, "Report of the Working Group on Energy Policy", Government of India, Planning Commission, New Dell (1979).

(32) Rietveld Piet, "Multiple Objective Decision Methods and Regional Planning", North-Holland Publishing Company (198

(33) Roberts, P.O., "Selecting & staging additions to a transportation network", Techniques of Transport Planning, (ed: J. Meyer) (1971).

(34) Steenbrink, P.A., "Optimization of Transport Networks", John Wiley & Sons(1974).

(35) Yashoshima Y., "Some Observations on Evaluation Methods Pertinent to Selection of Public Urban Transport System", Transport Decisions in an age of uncertainty. (ed: E J Vis (Apr 77) pp 399-409.

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